New Geological Instrumentation at the Microdevices Laboratory

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In Situ Exploration Technology Group
Device Research and Applications Section
Jet Propulsion Laboratory
California Institute of Technology

- In Situ Geochronology Instrument
- Atmospheric Electron X-Ray Spectrometer
- Nuclear Magnetic Resonance Spectrometer
- Atomic Force Microscope
- Microseismometer
- Microhygrometer
- Micro-Scale Fluidic Devices

In Situ Geochronology Instrument

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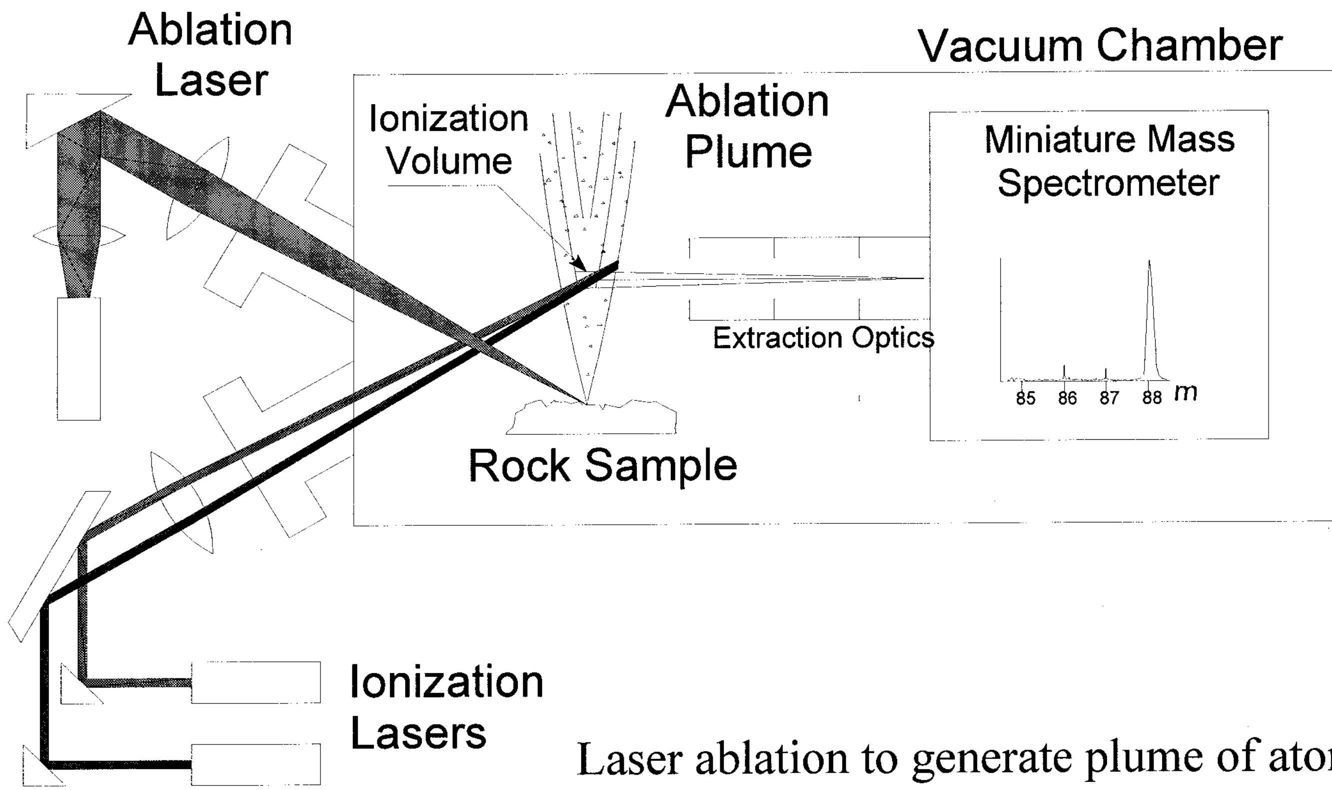
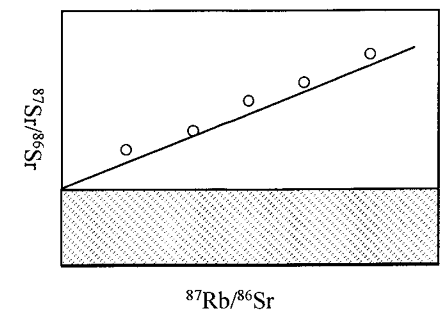
Funding
NASA (CETDP)
NASA (PIDDP)

Motivation
Crystallization ages of igneous rocks.
Calibration of Martian cratering record.

Readiness Level
Breadboard system is in development.

In Situ Geochronology Instrument





Laser ablation to generate plume of atoms, ions, and molecules.

Laser resonance ionization to selectively ionize Rb and Sr.

Ion trap mass spectrometry to measure Rb and Sr isotope ratios.

Multiple grains to determine isochron.

Does not require a chemical separation stage between sampling and ionization, minimizing complexity and consumables.

In Situ Geochronology Instrument

Laser Resonance Ionization

Electrons are removed from atoms by successive promotion to higher-level excited states until the ionization potential is reached.

Shown here are (—) demonstrated, (---) modeled, and (==) schemes for Rb and Sr.

Resonance ionization of Sr has been demonstrated in our laboratory.

Advantages

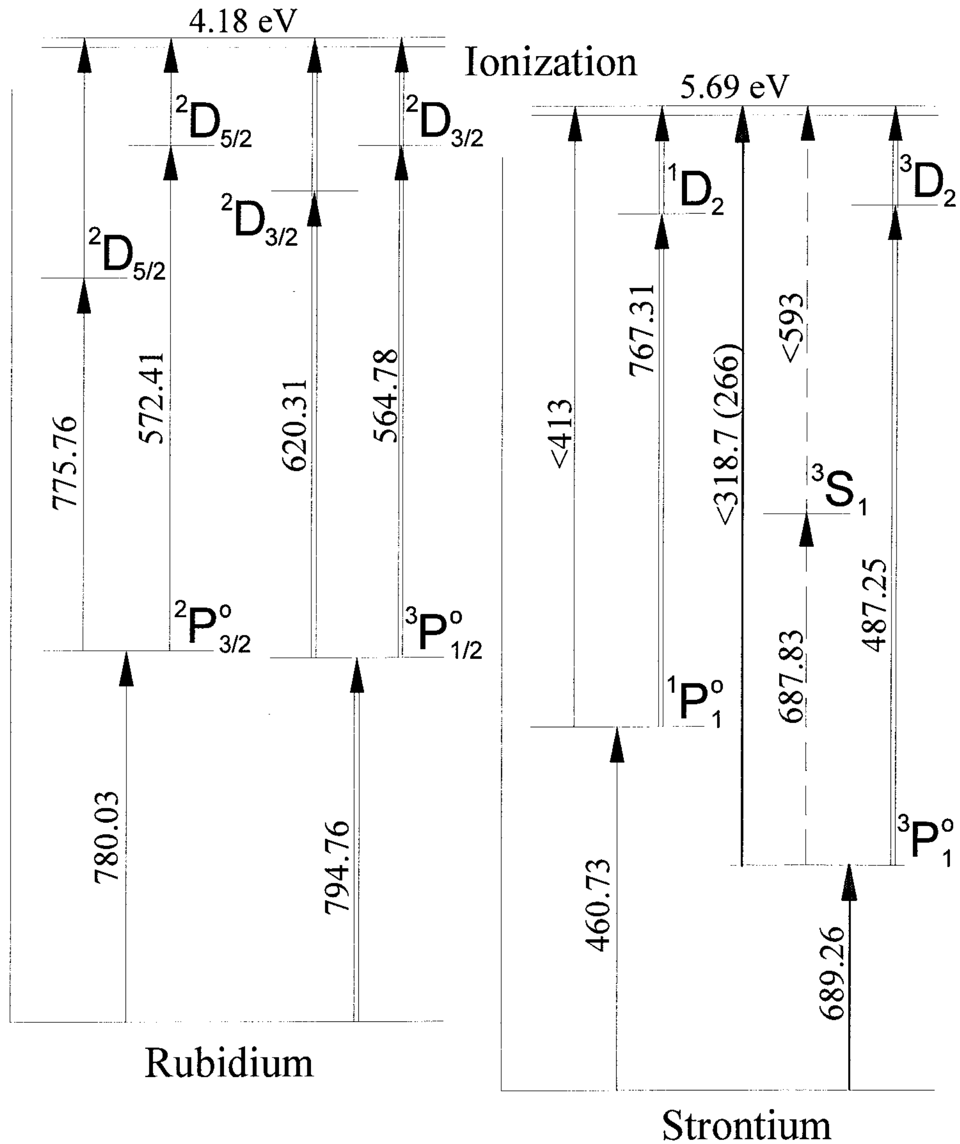
Eliminates wet chemistry by selectively ionizing only specific elements.

High ionization efficiency compared to other techniques.

Challenges

Identify tunable narrow-linewidth semiconductor lasers having appropriate wavelengths.

Calibrate ionization rates for even/odd isotopes.



In Situ Geochronology Instrument

Laser Ablation

A pulsed high-power laser is focused on a rock sample. Thermal, chemical, and electronic interactions trigger formation of a plume consisting of atoms, ions, molecules, and particulates.

Laser ablation of silicate minerals in our laboratory was found to preserve stoichiometry for major elements.

Advantages

Direct sampling.

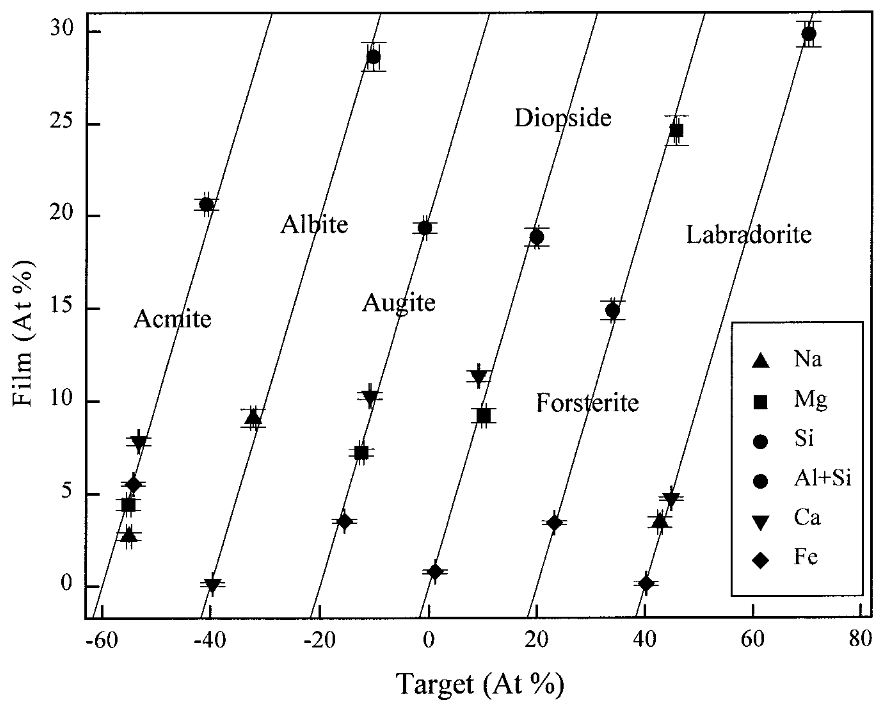
Mechanical simplicity.

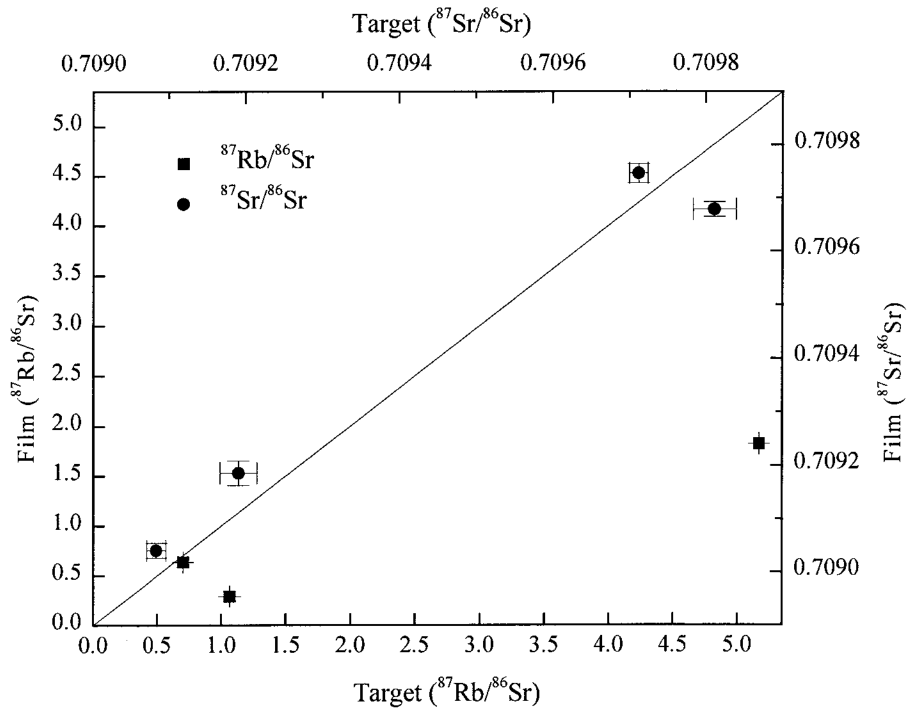
Challenges

Develop robust compact laser.

Evaluate element and isotope stoichiometry effects.

Develop feasible scheme for sample transport.





Atmospheric Electron X-Ray Spectrometer

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Funding

NASA (CETDP)

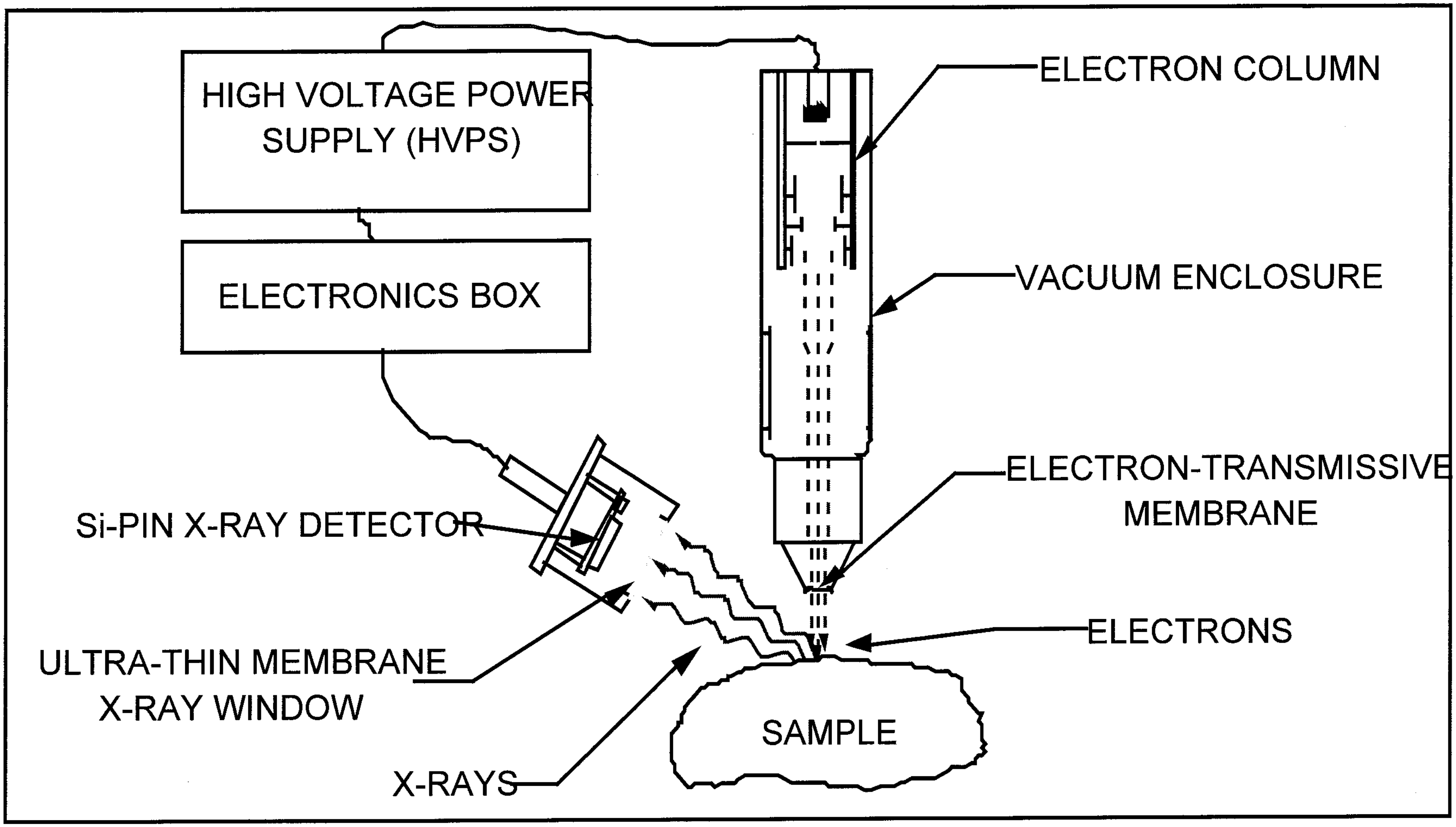
Motivation

Mineral compositions.

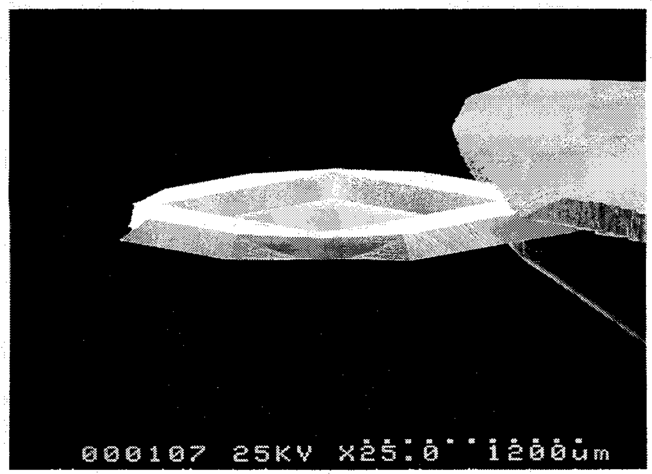
Readiness Level

Atmospheric Electron X-Ray Spectrometer

An electron beam is used to excite characteristic x-rays. Thin electron-transparent x-ray-transparent membranes isolate the electron column and x-ray detector from the planetary atmosphere.



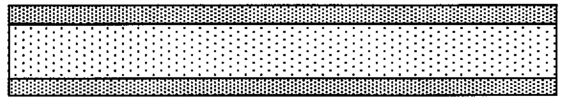
Membrane Fabrication



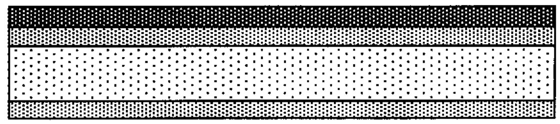
Scanning electron micrograph of SiN membrane.

Thickness ~ 200 nm

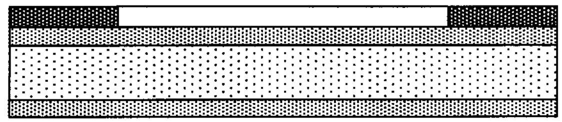
Radius ~ 0.5 mm



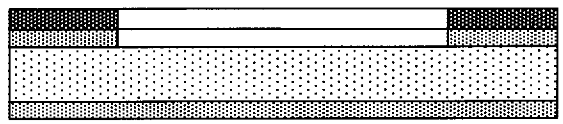
Coat Si wafer with SiN.



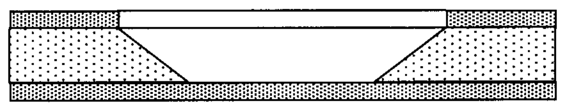
Spin on photoresist.



Expose and develop.

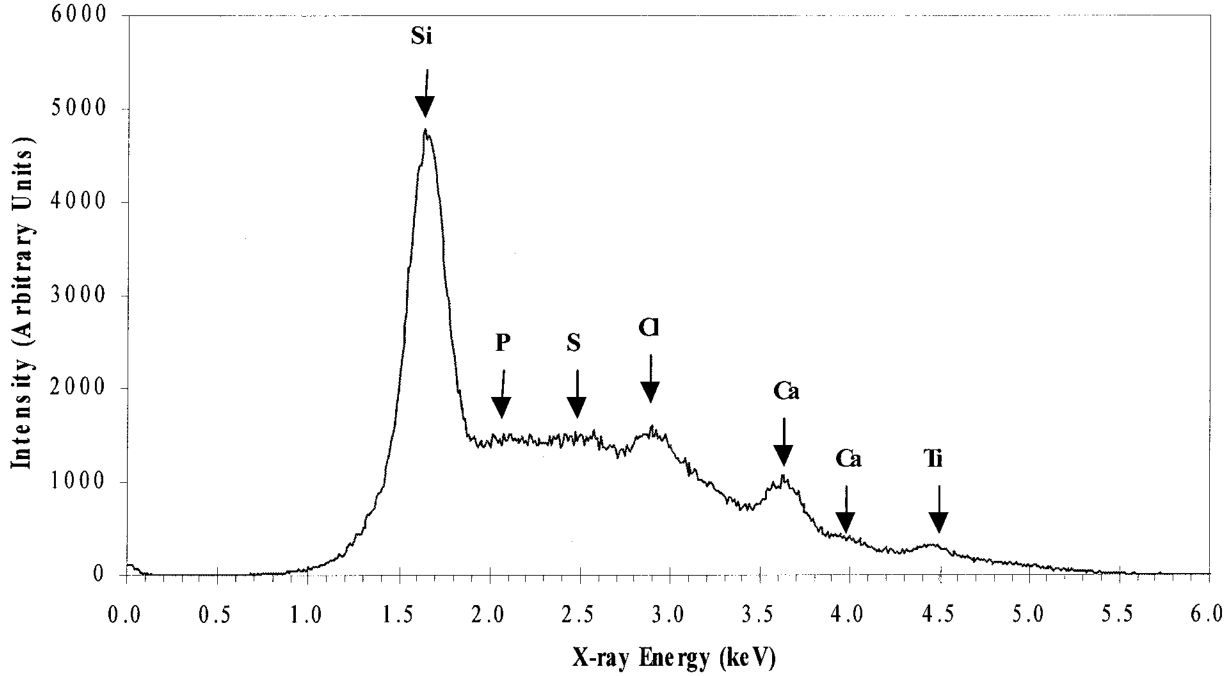


Transfer photoresist pattern to SiN using reactive ion etching.



Use SiN as mask for wet etching of Si to expose membrane.

Atmospheric Electron X-Ray Spectrometer



Compound	Weight %
SiO_2	34.5
Al_2O_3	18.5
TiO_2	3.0
Fe_2O_3	12.4
MnO	0.2
CaO	4.9
MgO	2.7
K_2O	0.5
Na_2O	1.9
P_2O_5	0.7
Volatiles	21.8

Challenges

Develop detailed understanding of the instrument operation.

Build stand-alone prototype

Explore other effects, i.e. cathodoluminescence, imaging etc.

Force Detected Nuclear Magnetic Resonance Spectrometer

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Funding

NASA (CETDP)

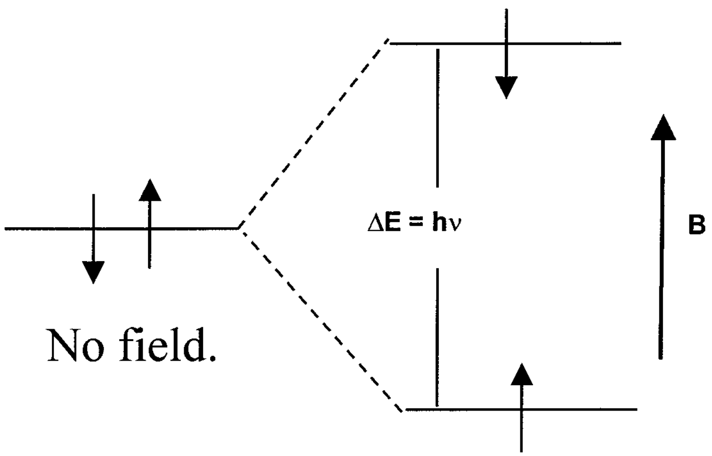
Motivation

Water, water states, mineral phases, and mineral compositions.

Readiness Level

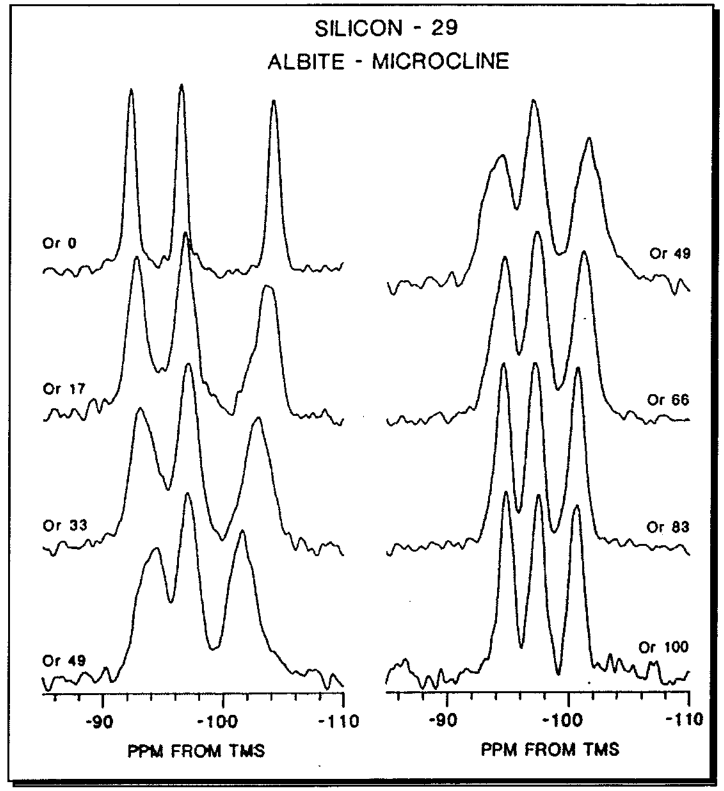
Nuclear Magnetic Resonance

Chemical shifts result from electronic shielding anisotropies, dipole-dipole interactions with nearby nuclei, and quadrupole moment interactions.



No field.

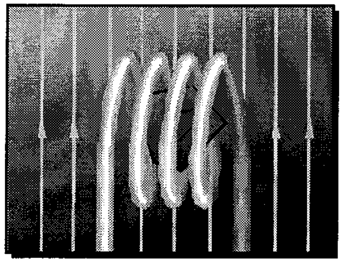
Applied magnetic field causes Zeeman splitting of energy levels.



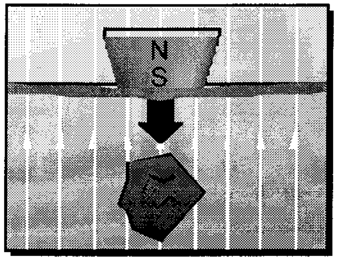
Three distinct ^{29}Si NMR lines corresponding to three types of Si sites in Si-Al ordered feldspars.

R. Kirkpatrick, Rev. in Miner. 18, 341 (1988).

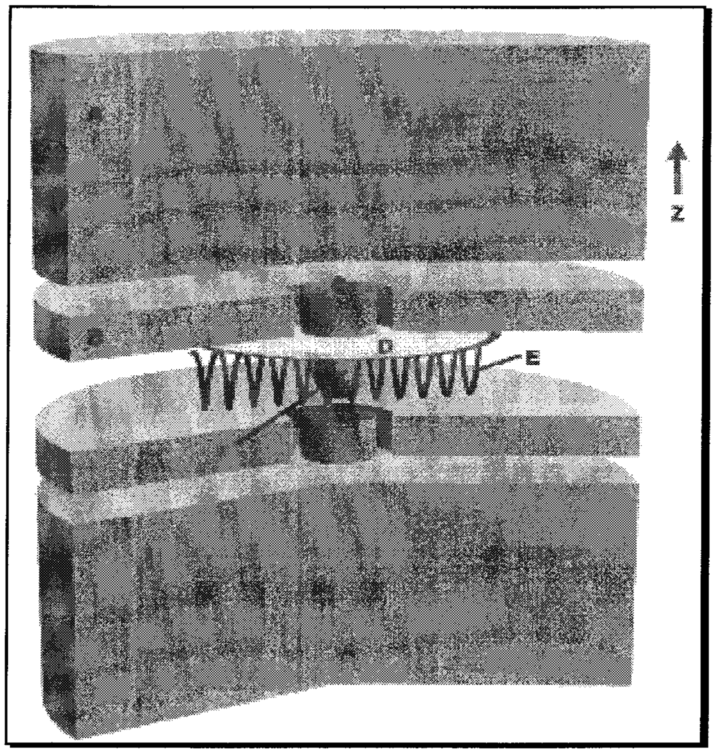
Force Detected Nuclear Magnetic Resonance Spectrometer



Inductive Detection



Force Detection



Detection

Force detection has a higher signal-to-noise ratio than conventional inductive detection for sample sizes of less than 1 mm.

Structure

Ferromagnets (A, B) provide a homogeneous magnetic field at the sample (F).

Sensor magnet (C) is mounted on a membrane (D) to form a harmonic oscillator.

RF coil (E) allows arbitrary pulse sequences. Longitudinal magnetization is cyclically inverted at the mechanical resonance frequency to drive the oscillator.

Fiber optic interferometer (G) detects the oscillator amplitude.

Challenges

Microfabrication of magnets and oscillators.

Handling and locating of samples.

Atomic Force Microscope

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Funding
NASA

Motivation
Size, shape, and composition of dust and soil particles.

Readiness Level

Atomic Force Microscope

Scanner

Electromagnetic coil actuators are used to decrease volume, power, and voltage.

Arrays of cantilevers are used to increase robustness.

Electronics

Cantilever deflection is measured using a piezoresistive Wheatstone bridge.

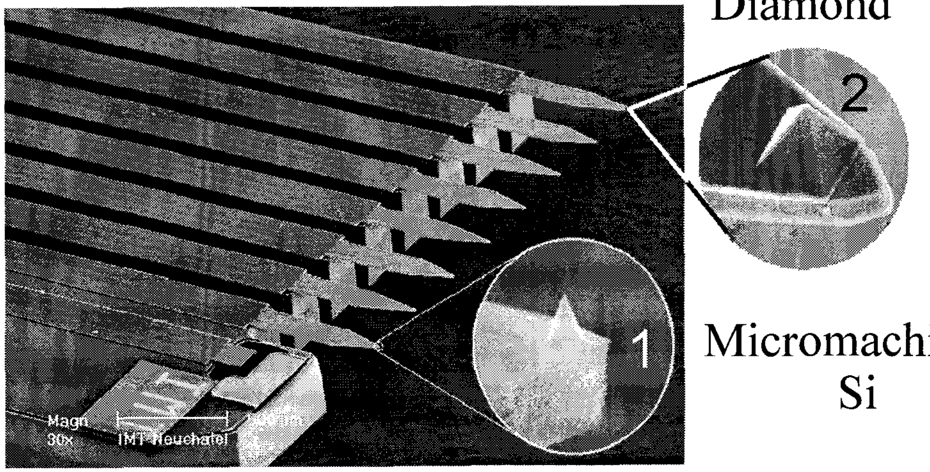
Reference resistor on a separate cantilever is used to compensate for thermal drift.

Operation

Dynamic mode reduces displacement of particles and cantilever crosstalk.

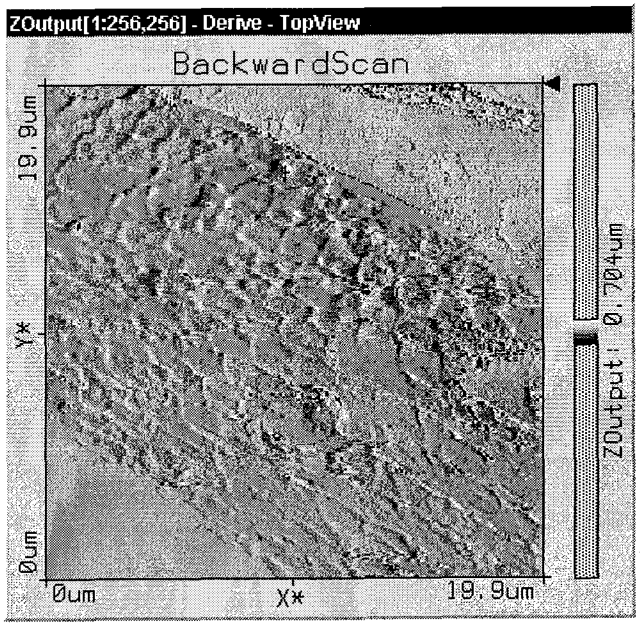
Noise is approximately 2 nm.

Can be used in vacuum, gases, and liquids.



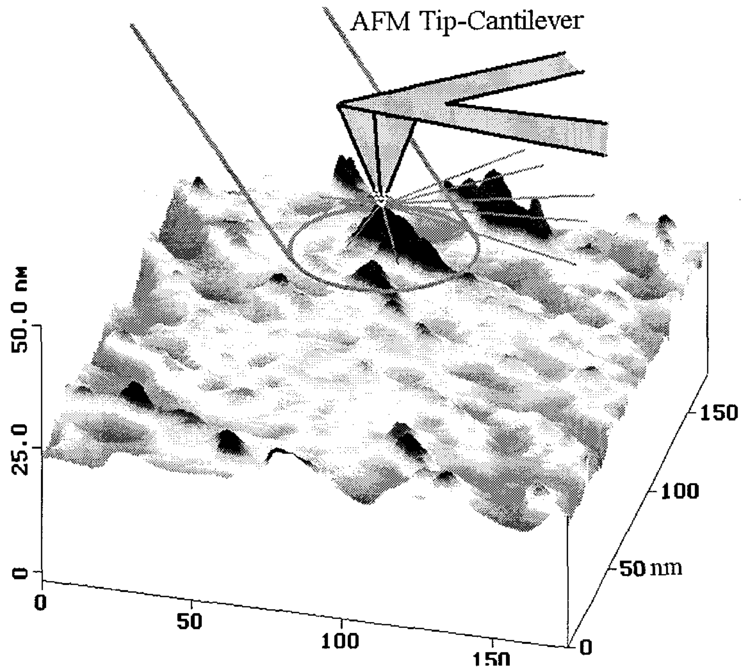
Molded Diamond

Micromachined Si



Diatom Image

Atomic Force Microscope



Infrared Absorption Spectroscopy

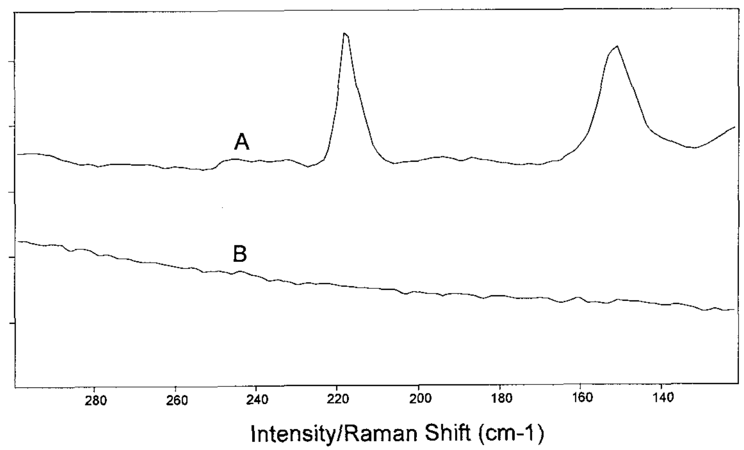
Cantilever deflection is used to detect thermal expansion due to absorption of energy from an incident beam.

Raman Spectroscopy

Metallized tip is used to produce an enhanced local surface effect, possibly due to electromagnetic filed enhancement or charge transfer resonance.

A Beam is focused near the metallized tip.

B Beam is focused far from the metallized tip.



Microseismometer

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Funding
NASA **(OSS)**

Motivation
Evolution of Earth-like planets.

Readiness Level
Field deployable system is in development.

Microseismometer

Suspension

Springs are continuous membranes to maximize robustness.

Spring-mass structures are distributed vertically to maximize compactness.

Stack is integrated with Au-In bonding to isolate vacuum and to maximize Q.

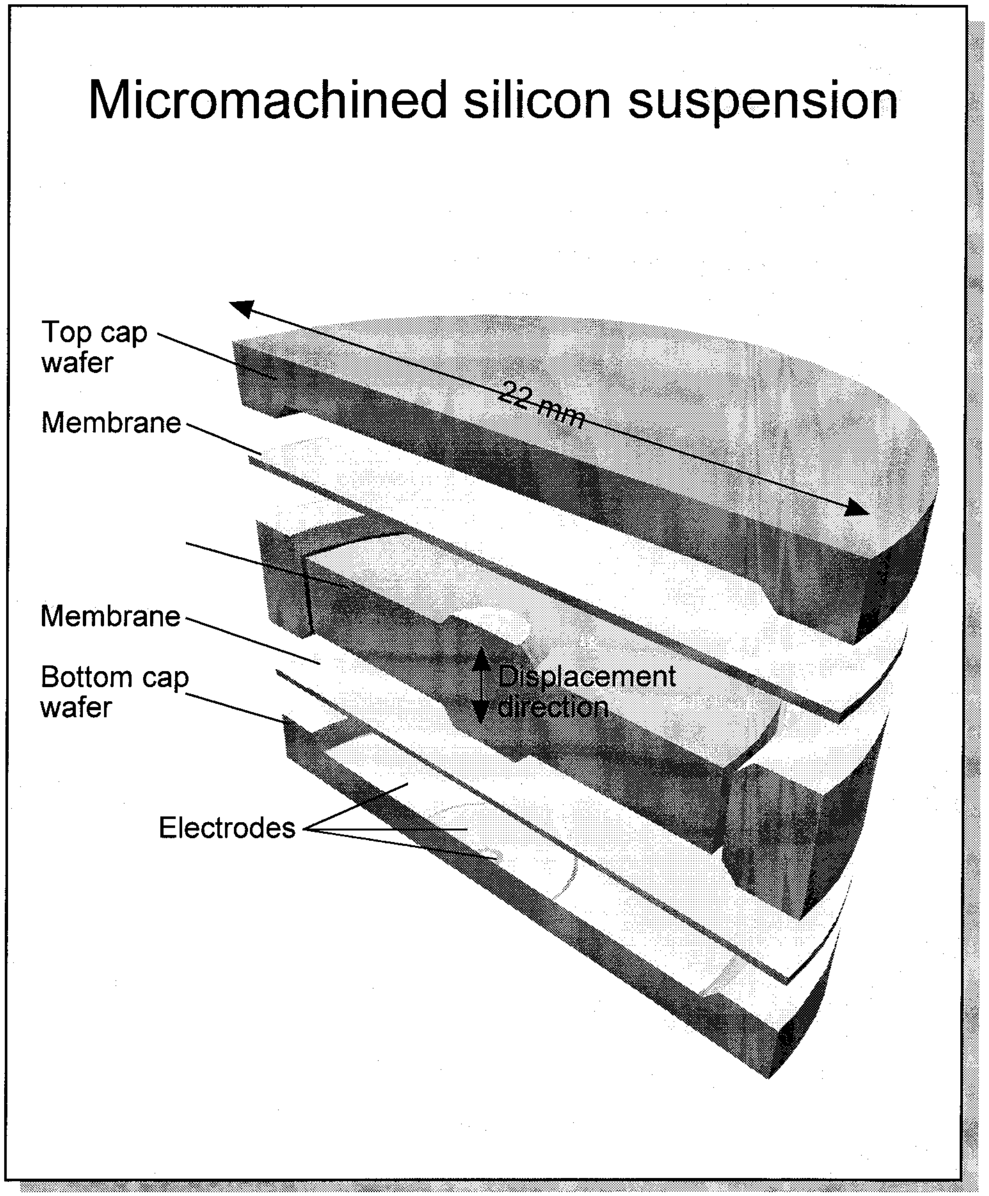
Transducer

Switched capacitor type.

Sensitivity of 2×10^{-11} g/Hz.

Bandwidth of 0.1-1000 Hz.

Power of 2 mW.



Microseismometer

Control

Electronic leveling to allow autonomous deployment.

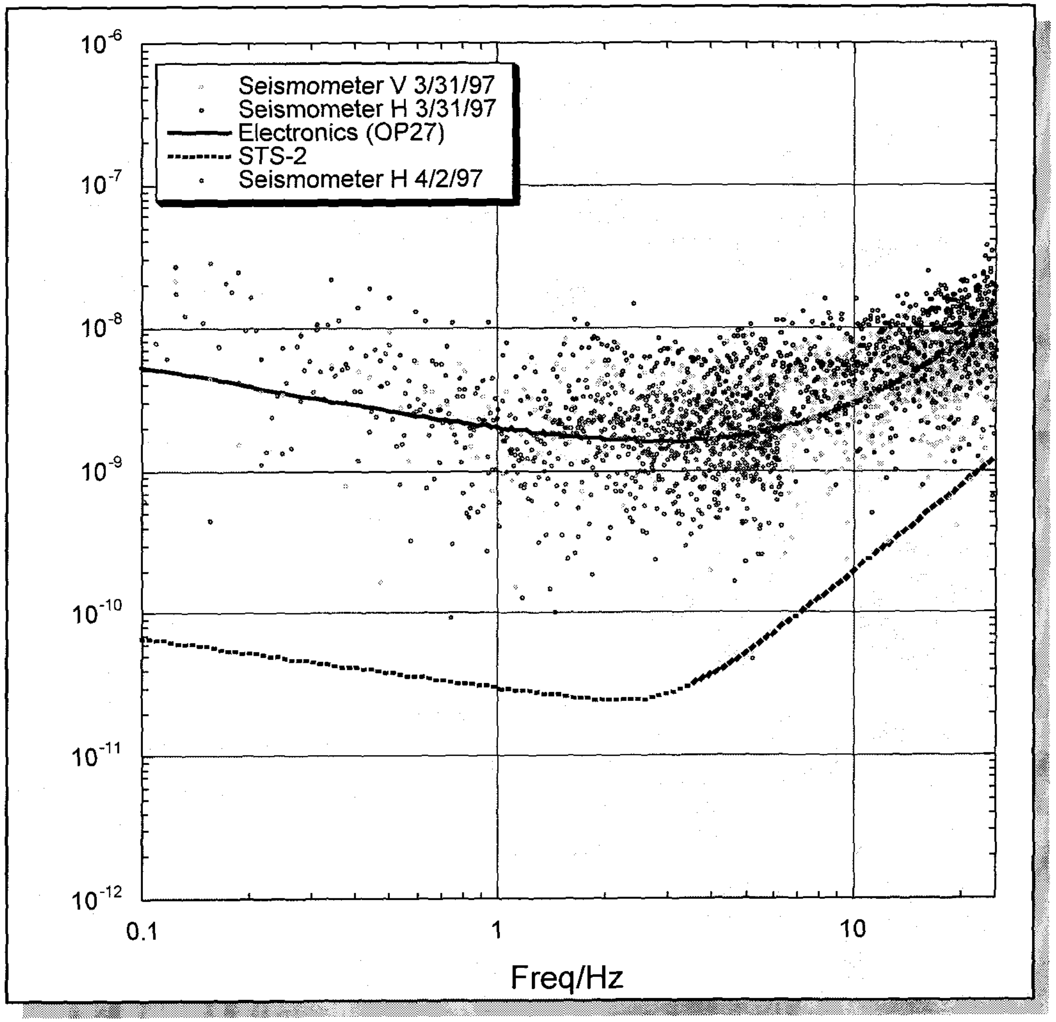
Two separate force feedback loops.
DC loop to center the proof mass.
AC loop for the seismic signal.

Noise

One part in a billion at 1 Hz.

One to two orders of magnitude above conventional seismometers.

Equal to theoretical limit of current electronics.



Microhygrometer

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Funding

NASA (CODE YS & CETDP)

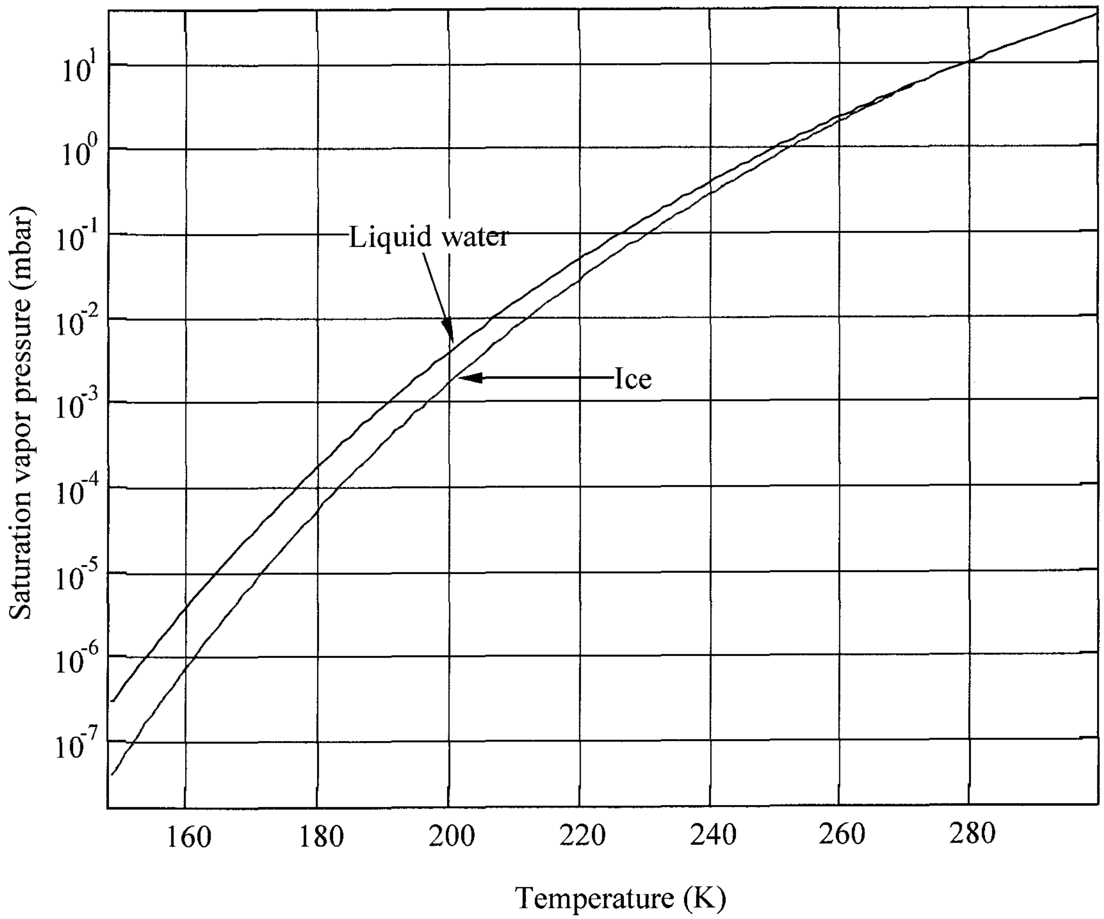
Motivation

Atmospheric chemistry, climate, and weather.

Readiness Level

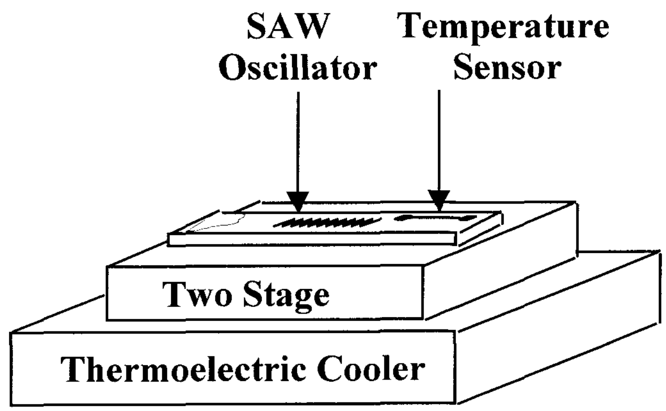
Radiosonde and CAMEX-3 validation flights completed.

Microhygrometer



Surface Acoustic Wave Dewpoint Hygrometer

Condensation on surface induces change in surface acoustic wave frequency.



Microhygrometer

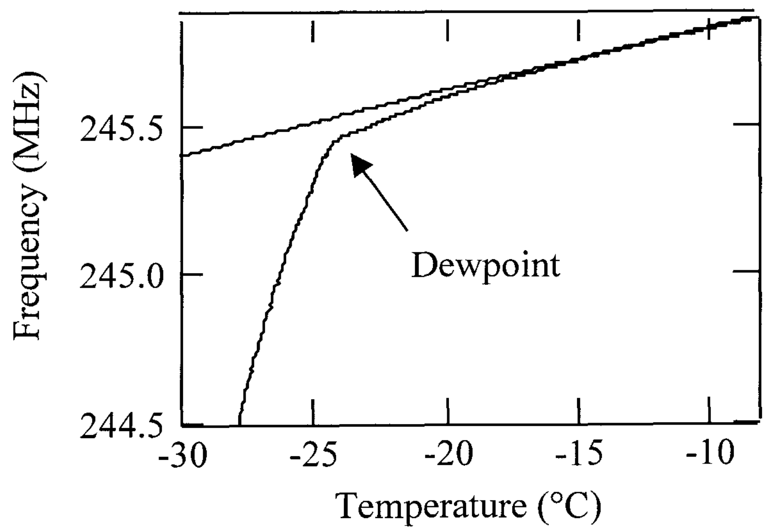
Temperature Control

Frequency depends on temperature and condensation.

Below dewpoint, condensation accumulates.

Abrupt change in slope when ramping through dewpoint.

Discrete dewpoint measurement.

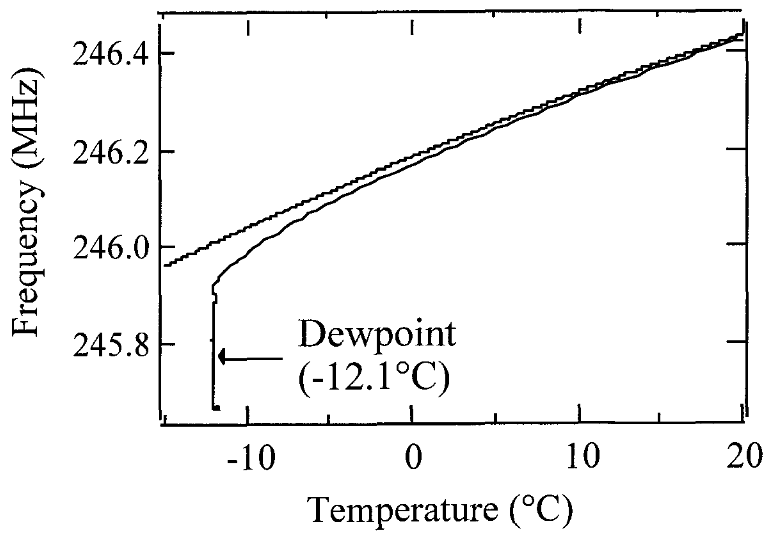


Frequency Control

Temperature depends on frequency and condensation.

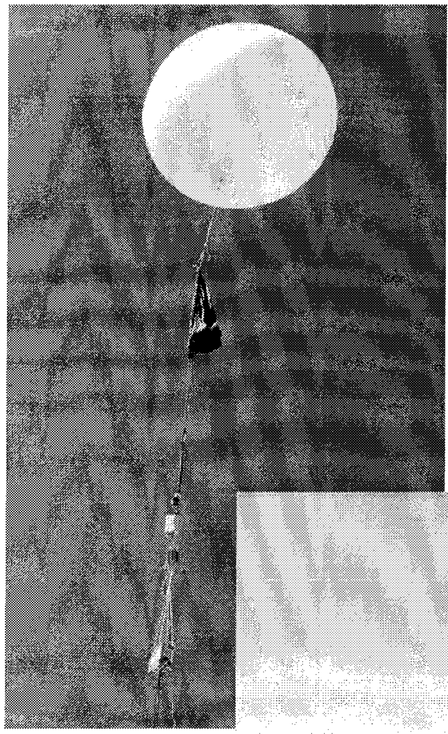
Below threshold frequency, equilibrium with water vapor determines temperature.

Continuous dewpoint measurement.



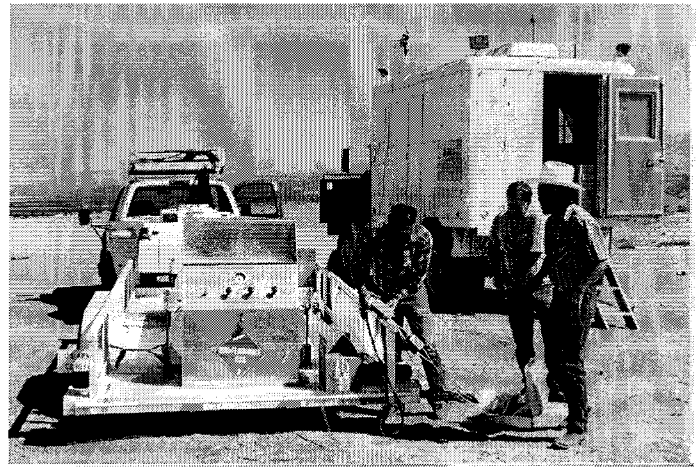
Microhygrometer

Radiosonde Flight

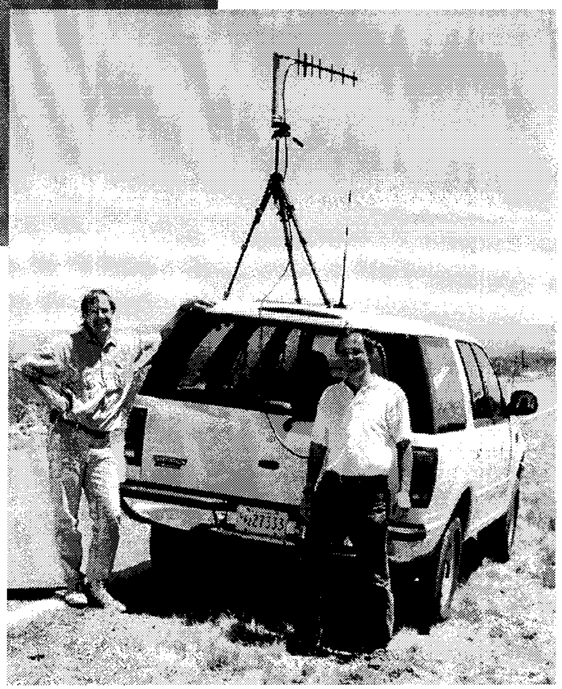


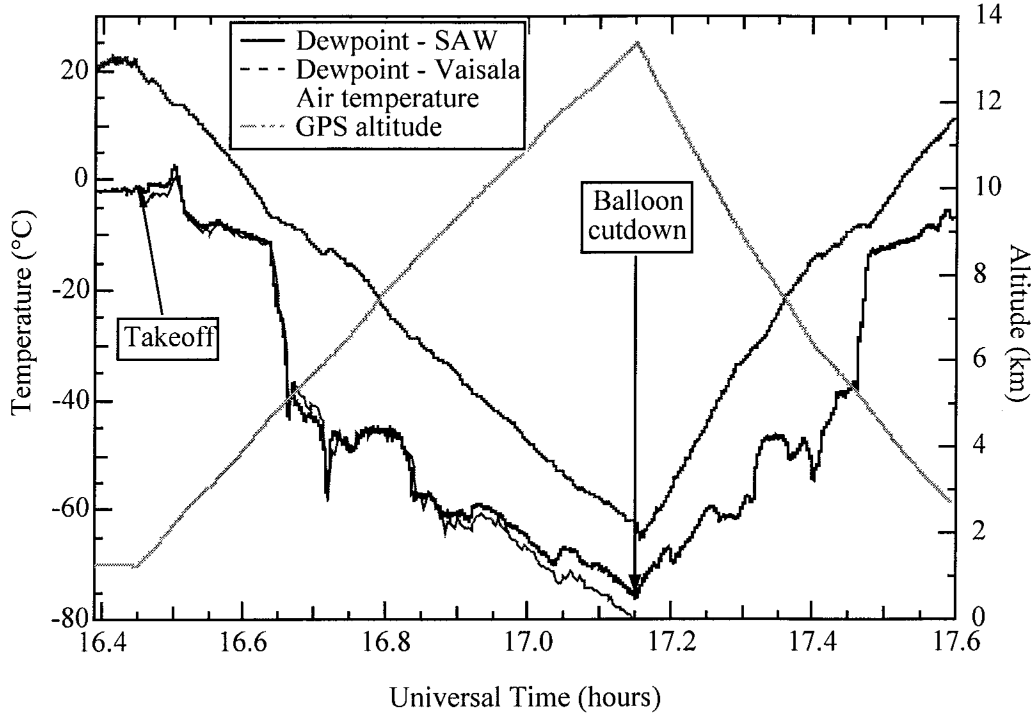
Balloon Payload

Launch Support



Ground Station

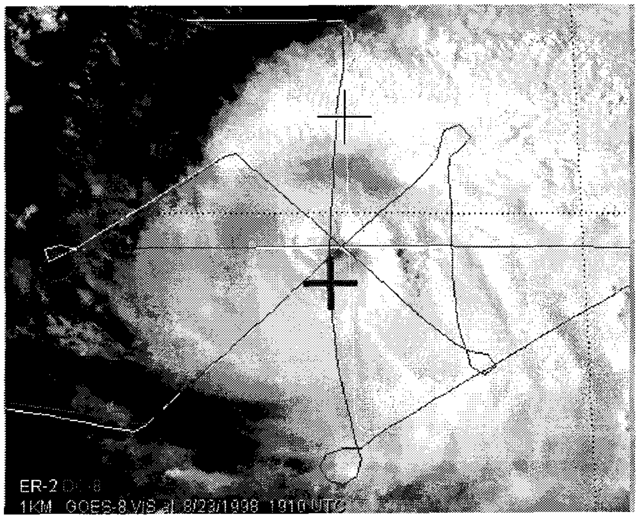




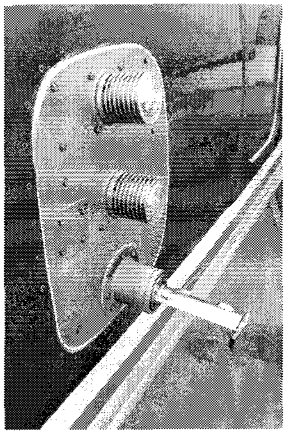
Microhygrometer

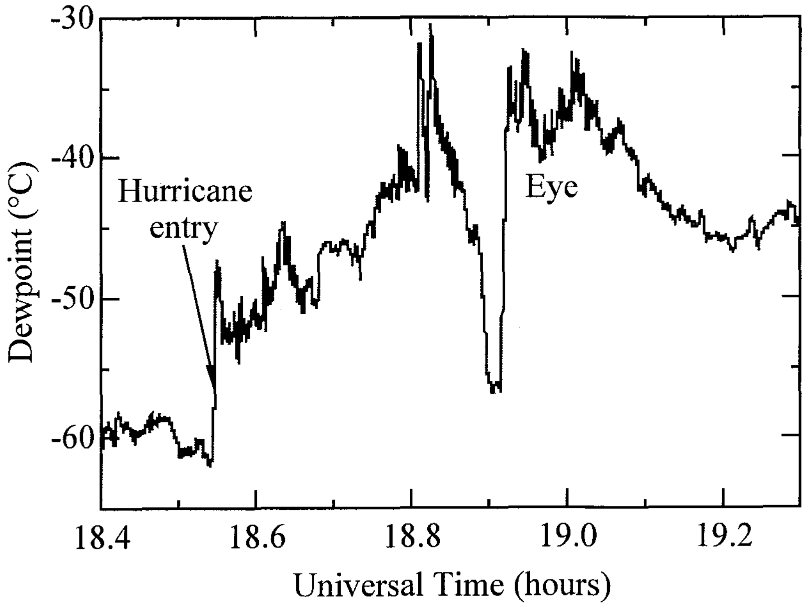
CAMEX-3 Flight

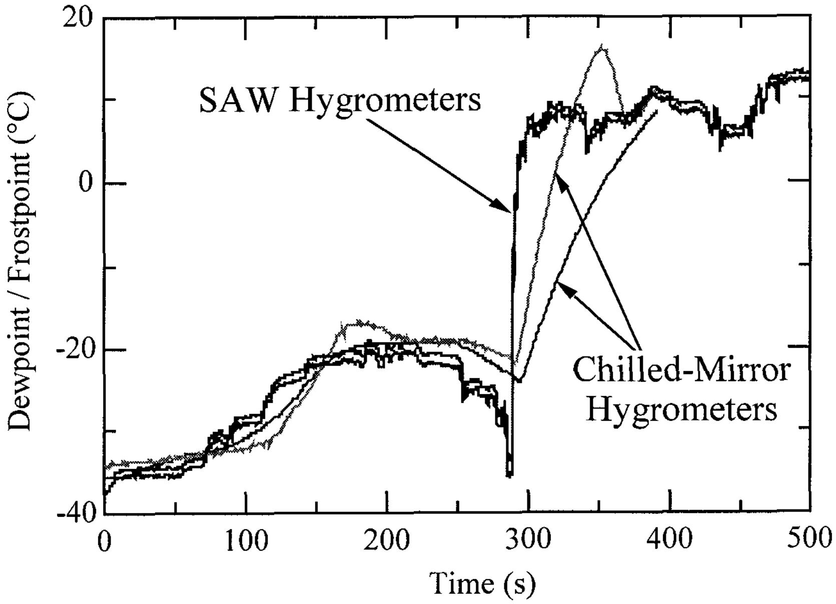
NASA DC8	30,000 ft	Pink
NASA ER2	65,000 ft	Yellow



Hurricane
Bonnie







Micro-Scale Fluidic Devices

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Funding
NASA (CODE U & CETDP)

Motivation

Wet chemical analyses on Earth-like planets, space vehicles, and space stations.

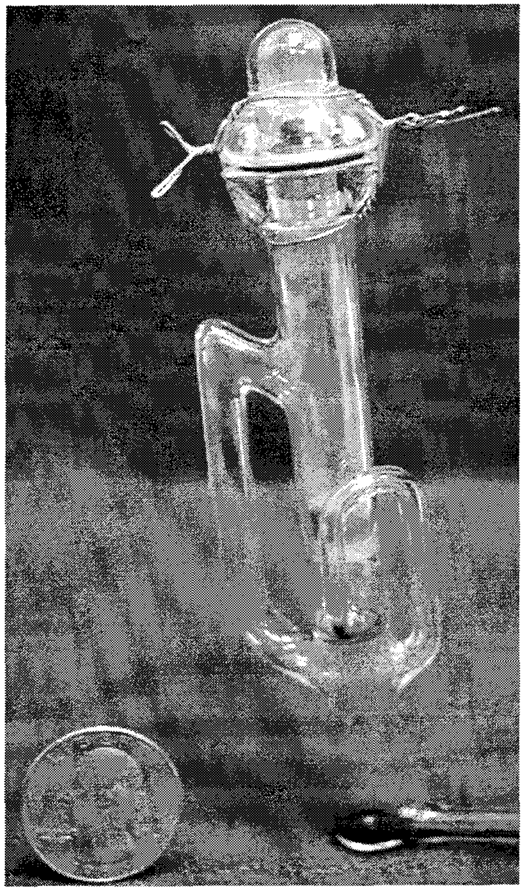
Readiness Level

Concept study is in progress.

Micro-Scale Fluidic Devices

Soxhlet Extractor

Can be used to extract a variety of inorganic and organic compounds from solids such as sediments, soils, and sludges.



Sample and solvent are placed in flask and heated.

Solvent vapor rises in large external tube, condenses, and interacts with sample.

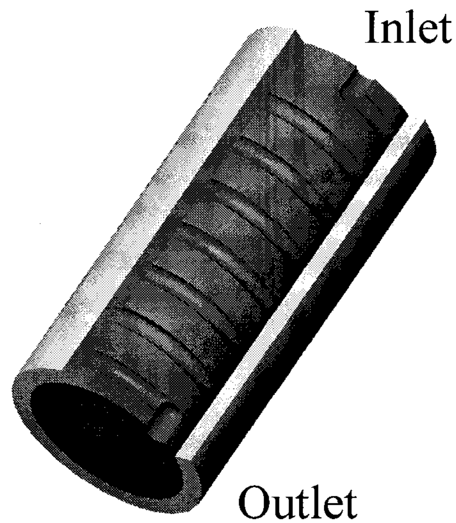
When solvent liquid level reaches bent tube, solvent liquid is returned to flask for reuse.

JPL

Micro-Scale Fluidic Devices

Capillary Ion Chromatograph

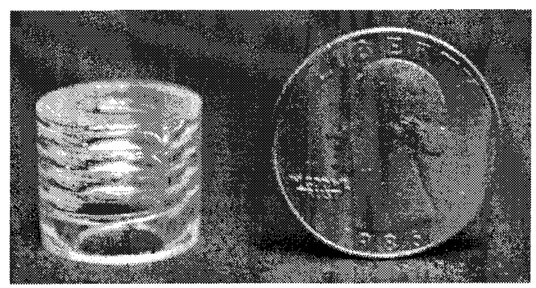
Technique can be used to separate and detect a large number of trace ionic species including F^-, Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{-2}, HPO_4^{-2}, Li^+, Na^+, K^+, Mg^{+2}, Ca^{+2}, Sr^{+2}, Ba^{+2}.



Technique can have sensitivities of parts per trillion if pre-column concentration and post-column conductivity suppression are used.

Chromatography column is machined in a glass cylinder to maximize compactness.

Glass cylinder is enclosed by a glass sheath to isolate vacuum.



Miniature syringe pump driven by a stepper motor is used to achieve differential pressures as high as 7000 psi.

Ions are separated using standard ion exchange resins and column packing materials.